WORKSHOP ON

THE USE OF AGRO-ECOSYSTEMS IN TEACHING ECOLOGY

Shumant 22/6/77

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Sponsored by

DEPARTMENT OF ENTOMOLOGY
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Workshop Schedule

22nd June

9-00	Registration
9:30 - 10:30	Ecology courses and their enviornment
10:30 - 11:00	Break
11:00 - 12:00	General concepts of energy budgets and ecosystem structure.
12:30 - 1:30	Lunch
1:30 - 3:00	Films
3:00 - 5:00	Practical data collection.

23rd June

9:30 - 11:00	A general model for Indian Agriculture
11:00 - 11:30	Break
11:30 - 12:30	Discussion
12:30 - 1:30	Lunch
1:30 - 2:30	Tradeoffs , efficiencies and cost benefit relations.
2:30 - 3:00	Break
3:00 - 4:00	Sericulture and grain farm models
4:00 - 5:00	Open discussion Agro-ecosystems in teaching.

Convener — Dr. G.P. ChannaBasavanna
Professor and Head, Department of Entomology

Coordinators — 1. Dr. R.V. Krishnamurthy
Associate Professor of Zoology

2. Mr. R. Balasubramanian
Assistant Professor of Entomology.

Director — Dr. Rodger Mitchell
Visiting Fulbright Professor, Department of Entomology.

Preface

These workshop materials are offered with the hope that they will stimulate Indian ecologists to use more examples from agricultural systems and also provide reference materials for field projects and research on Indian agro-ecosystems.

Numerous Indian biologists have given me the information and advice that made it possible to prepare this. In the University Dean K. Ramakrishnan and Prof. G.P. ChannaBasavanna gave me much aid and encouragement. The basic support for this work came from the United States Educational Foundation in India.

Hebbal
May 27, 1977

R. Mitchell

The Ecology of Ecology Texts and Teaching: Does Environment Matter?

Ecology is the study of the processes responsible for the conversion of light energy into the biomass of plants (called producers) and the behavioral and physiological processes that determine the numbers and abundances of the animals that eat the plants and other animals, or both (called consumers). In addition to these organisms, there are sets of organisms responsible for the decay of dead plant and animal matter(decomposers). These often neglected organisms play a crucial role in completing the cycles of nutrients in natural communities.

Ecologists attempt to divide the world into biotic communities such as forests, paddy fields, lakes, coral reefs and so on. Each of these communities consists of a set of producers, consumers and decomposers and each community may be distinguished by its location as well as the set of species that make up the community. A unique set of species form the forest of a particular region but all the forest communities under a given set of conditions will have a similar appearance even though the species differ. Communities can be grouped together on the basis of their appearance and forests as a group are radically different from a paddy field, lakes or coral reefs.

The structure of each community is the consequence of adaptations to the environment. Wet warm environments are occupied by forests. Marshes and paddy,which is a marsh plant, occur where water levels fluctuate widely over the year . The local community is the outcome of local conditions and the correlations between local conditions and community structure allows some kinds of predictions to be made. If these correlations are at all reliable, then there are likely to be some common set of biotic processes that operate to produce forests where it is constantly moist and grasslands where the total rainfall is the same but it falls in only one season of the year. If the operation of the biotic processes can be explicitly defined, then a new kind of prediction is possible. Such predictions would be based on an understanding of how communities operate in contrast to correlations that simply define outcomes from past experience.

At this point, ecology is in search of models for general processes even though the basic tools are still at the stage of correlation and description. The broad outlines of the biological processes are known so that

the general elements of a community can be defined from fundamental processes. This is a considerable achievement but it still leaves ecology in quite a different situation than genetics of physiology. The genetics of Indian cattle are governed by the same principles as that of American blacks, guinea pigs, cobras and orchids. Physiology - say respiration - is governed by generalizations as universal as those of physics and chemistry.

Ecology is different. Perhaps the basic laws governing ecological processes will be developed in time but at present the elements of ecology are descriptive. For example, the chemical processes of photosynthesis follow known patterns and the process can be measured but there is no explicit model to explain why plants mold their photosynthates into a tree in one set of conditions and why a grass-like plant is adaptive in another set of conditions.

With ecology at the level of description and correlation it means that the instruction given in a course ought to deal with familiar communities. An Indian tank shows a particular pattern of seasonal change and there are no general process models that cover tanks, temperate lakes and temporary ponds. Each one is unique because ecology still operates at the level of correlation and description. There are a common set of elements must be described so that studies of tanks, lakes and ponds can be compared and there is general agreement on what to measure. Still the interpretation of each set of data is an independent exercise in analysis.

A functional picture of community ecology that makes predictions and developes generalizations from models for biotic processes will have to be based on studies of responses of organisms to their environment. Since the combinations of species and local conditions are unique at each spot on earth, each ecologist deals with problems involving quite different combinations of elements. It is easiest to show students how to describe structure and function in a familiar biotic communities. Then the generality of what they do can be shown to apply to unfamiliar systems.

If one asks what portion of an ecology text is essential and what portion represents optional examples taken from the environment of the author, there is no easy way to find an answer because there is only one sample of text books. All the major books are written by western authors for use in the urban industrialized countries of Europe and North America. (The "Indian" ecology books, are imitations of western text books, an allegation I will support below).

It is instructive to analyse the three western text books available in India to find out exactly what a western text book uses to illustrate ecological principles. Since most examples are accompanied by an illustration, this analysis can be based on the figures and tables. These can be classified as: General examples that fit any situation and cannot be identified with a particular community, for example, unlabelled energy flow diagram showing the relations between trophic levels. Natural examples in which a particular natural community, forests, desert, pond, etc. are used to establish a point, Agricultural, Industrial or Urban examples are based on one of these systems. These classifications are not absolute but they are good enough to reveal the general patterns in the three texts.

	General	Natural	Agricultural	Industrial Urban
Odum (1971)	.27	.48	.12	.12
Kormandy (1969)	.39	.52	.05	.06
Kendeigh (1974)	.50	.47	.01	.02

Obviously this could be used to argue that ecology, as a science, is the study of natural systems and that may be a common feeling among ecologists. Perhaps most ecologists are naturalists and they are regularly in the fore-front of the present conservation movement. But is it appropriate to conclude that "pure" ecology is limited to the study of natural communities? Is "applied" ecology a secondary or ancillary field?

This is a question of great importance in India. If ecology has little or nothing to do with applied systems, then, the ecology courses in India will have to deal with parts of India that are outside of the experience of most students. Parks in India are small and remote. Pieces of reasonably natural vegetation with wild life in them are not found near many urban centres. Important as the small areas of natural vegetation are, for the survival of endangered species, they are, in fact, used by very few Indians. An ecology course devoted entirely to natural communities will deal in an abstract way with things that are not a part of the life of most students in India.

....4

Before concluding that the basis for pure ecology can only be studies of natural systems, it is necessary to determine why western ecologists do not use many examples from agricultural, urban and industrial systems. Few examples are taken from urban and industrial systems because those systems are so highly modified that the usual ecological components are either not operating or are greatly altered.

Although agriculture is a biological process, the agricultural systems in the West are dominated by chemicals. Weeds are eliminated by herbicides, chemicals kill insects and the energy put into cultivation and fertilizers often equals the energy harvested in the crop. Such agriculture is a kind of engineering in which ecological processes are suppressed rather than used and exploited. For this reason western ecologists do not often use examples from agriculture.

There is a second reason for not using agricultural examples and that is the fact that very few students in an American University have any experience with agriculture. When they leave the city, they often go to natural areas in which wild life is found. The area of parks in the United States is ten times the area of Indian parks. Over half the Americans visit a park each year and 16 per cent of the Americans camp and live in a natural area each year. A very large portion of the campers are young people from urban areas.

To test the idea that American students are more familiar with natural systems than agriculture, a group of first and second year students at Ohio State University (Columbus, Ohio, U.S.A) were polled. The University has a large aricultural college and is situated far from any major natural park area. The bias toward rural and agricultural experiences may be greater than average for American students, still about 95 per cent of the 1060 students polled had been to a wild life area in the last four years and also had close acquaintances who had visited parks. Nearly all the students (87 per cent) had seen a deer in the wild, regularly walk where they can see wild flowers and birds, and either hunt or fish in a natural area. About 60 per cent are from families more than two generations removed from farming. Less than 40 per cent have lived in an agricultural situation or are familiar with farm production problems.

Natural systems are familiar to nearly all American students and an American ecology course is likely to give students a better appreciation of the natural areas that are a major part in American life. Western ecologists give little attention to agriculture but it is presumptuous to think that these systems are ignored because agriculture per se is not pure ecology. Western agriculture is less well known to western students and also differs from much of the agriculture in South Asia. Western text books reflect the culture, resources and environmental concerns of their authors. If anyone doubts this, simply examine Odum (1971) to see how many examples are taken from Georgia, Kormandy (1969) to see how often he uses examples from Ohio and Pennsylvania and Kendeigh (1974) for examples from Illinois. What Odum talks about then using examples from Georgia is likely to be suitable for students in Illinois or Ohio and vice-versa. The questions Indians must address is whether the examples from Georgia are the best examples to use for teaching ecology in India.

There are Indian authored texts and, if these followed western pedagogical techniques, they would use indigenous examples to attempt to capture student interest. From 47 to 87 per cent of the examples in the three American texts are specifically identified or identifiable as being drawn from a particular community and 84 to 92 per cent of these examples are clearly North temperate. Six Indian authored texts that I will not identify beyond saying that they were all published in the 1970s differ sharply from American texts in having only 7 to 43 per cent of the examples identifiable as to the community. On the average 3 out of 4 examples were so general as to apply to anything. Indian authors also cite examples from temperate climates. From 33 to 100 per cent of that small minority of identifiable examples in Indian tests are from temperate climates. One can only conclude that either there are no examples from tropical research, which is false, or that Indian authors have on the average, concentrated on generalities to the point that very few substantive examples are used and there is little concern as to whether those examples are tropical or not.

Averages are misleading. One of the six books has 67 per cent of the identifiable examples drawn from the tropics and it uses twice as many identifiable examples as any of the other 5 Indian texts.

With this one exception the Indian authors appear to have created an indigenous texts by inventing a new approach to teaching. They select the most abstract and general arguments from western texts and eliminate nearly all the specific examples, western authors find essential for capturing student interest and showing how the generalities apply to the real world. The product may reflect the dreary drab outlines of a syllabus and thus be a comfortable solution to a bureaurocratic problem. But the texts do not reflect the accomplishments, capacities and aims of Indian ecologists. Our text books do give a clear idea of the environment of the United States and they reflect the activities of American ecolc-gists. With one exception, Indian ecology texts give the teacher and the students no help at all in applying concepts, inadequately described the environment of India (although the environments of the world were described) and, at times, go out of their way to avoid even mentioning indigenous systems.

These are serious charges that need documentation and two examples may be sufficient to establish the point. The soil fauna is important and most texts mention it. Two of the Indian texts have an elaborate illustration of soil organisms and termites, the most important and obiquitous soil organism in India, are left out. If students use the illustration as a guide to study, they will be deceived as to the soil fauna in India. Even more apalling was a list of venemous animals. Any Indian could name venemous animals directly from every day life but one Indian author gives the following sequence of examples i) rattlesnake (ii) tarantula iii) trap-door spider iv) red ant of the desert v) gila monster vi) skunk of Southwest America (sic). Setting aside the fact that the skunk is not venemous and the fact that the term "Southwest America" can apply to two continents, this list of six animals contains four animals that are strictly New World genera and excludes the most common venemous animals of India. These are extreme examples but they illustrate a pattern. Most Indian text books of ecology ignore the environment of India.

It is my argument that introductory teaching in ecology whether it is a part of a general subject at the college level or a course at the post-graduate level will fail unless it helps students understand their own environment. The text book, course materials and the teacher all share in this responsibility. The crucial questions from which a relevant indigenous science can be developed are: which systems are most familiar to Indian students? How can the general concepts and principles be applied so as to show how the science of ecology gives insights into the structure and operation of biotic communities?

The natural communities have been destroyed over most of India and the few remnants are remote areas that are not visited by many students. The major systems most familiar to Indian students are the agricultural systems. But many respond with the argument that these systems are artificial or applied ecology and cannot be used to illustrate pure ecology. "Pure" ecology needs to be defined. Consider a movie theatre and a termite colony: both are air conditioned, both are beautifully appointed, clean, orderly places that provide a modified environment for the comfort and pleasure of their respective species. Human beings paint walls or select marble to line the chambers, termites use saliva to finish walls and select calcium rich soils for their walls. The movie theatre is an artificial environment and the termite colony is natural - Why? The fundamental difference is that the termite colony is a community that survives on the continuous input of solar energy. Manipulation of the environment outside of the territory of the termite mound cannot affect the operation of that mound. What of the movie theatre? The energy used to build the theatre is not the current input of solar energy, it is non-renewable fossil fuel. Its air-conditioning is also operated from energy derived from fossil fuel. The only functional way that a movie theatre can be defined as artificial is that it uses supplementary energy from non-renewable sources. It is not powered from current solar inputs as the termitarium is.

The general distinction between natural and artificial systems is the use of fossil fuel to alter the environment rather than limiting the system to solar inputs. Pure ecology is the study of independent, self-sustaining systems based on current inputs of solar power. On that basis western agriculture can be defined as artificial because the inputs of mechanical and chemical energy derived from fossil fuel materially alter biotic processes. Indian agriculture is generally solar powered. The energy of people and bullocks comes from current inputs of solar energy stored as food. The crop systems in India receive, on the whole, very limited doses of chemicals.

There is no way to distinguish the natural systems of ants and termite from much of Indian agriculture except to say that Homo sapiens is an animal that, by definition creates artificial systems, whereas the work of Formicidae and Isoptera produces natural systems. That is an artificial anthropocentric distinction with no biological basis.

There may be a point at which it is difficult to say when the inputs of external energy are large enough to make the system artificial. On the average, Indian inputs of fossil fuel are 4×10^5 Kcal per hectare while the average hectare in the United States is affected by inputs of at least 6 million Kcal, nearly 2.5 times the Indian inputs. Clearly Indian agriculture is still biological, as contrasted to an engineered system, and the biologist is fully justified in treating it as nearly as "pure" biological system. There are many aspects of Indian agriculture that are completely solar powered and, therefore, as natural as termitaria, rat burrows and bird nests.

It can be argued that Indian agriculture is basically a biotic system and it is the only large scale biological community that is accessable and familiar to a majority of Indian students. The concepts of limiting factors, succession, animal population dynamics, life tables, energy budgets and ecosystem analysis can all be illustrated clearly and unambiguously from agricultural systems. If a student can be shown how to apply general ecological principles to this familiar part of their experience, it should be easier to develop an understanding of the less familiar natural areas.

The content and approach used in Indian ecology courses should be a reflection of the environments in India. Neither the wild life nor the biological aspects of agriculture can be neglected. Agriculture is now neglected and offers unique opportunities for developing new materials for the teaching of ecology.

If Indian ecologists grasp the opportunity to study the ecosystems of the purely biological Indian agricultural systems they can make fundamental contributions to the science of ecology and can develop the essential materials for an indigenous approach to ecology that will make their courses more useful for their students. The examples used in courses can be relevant and are likely to lead to fundamental contributions to an understanding the major natural resource of India - the farms and the farmers of India.

The place to begin work in this new field is with ecosystem models which begin with statements of general biological relations. These preliminary models can then be refined into complex and precise models for specific systems. The latter refinements are not possible at this time but the basic data for general models is available.

References

Kendeigh, S.C., 1974. Ecology with special reference to animals and man. Prentice Hall of India.

Kormandy, E.J., 1969. Concepts of ecology. Prentice Hall, N.Y.

Odum, E.P., 1971. Fundamentals of ecology, W.B.Saunders, Philadelphia.

Results of a Questionnaire given to American College students in the Winter of 1977.

	% answering yes. 1	2	3
1. Have you visited a park, wildlife reserve or other natural area in the last 4 years.	96	94	100
2. Do you have a friend or relative who has visited a State or national wildlife area?	95	99	98
3. Do you walk in areas where you can see wild flowers and birds several times a year?	[illegible]	99	100
4. Have you seen a wild deer?	87	88	100
5. Have you ever gone hunting or fishing?	87	88	84
6. Was your father or grandfather a farmer?	42	42	53
7. Have you ever lived on a farm or in a village that is primarily rural and agricultural?	42	32	49
8. Do you regularly read about the problems of weather, crop production and harvests?	38	10	33
9. Have you visited a farm in the last year?	67	57	82
10. Can you identify most of the crops you see growing in fields and gardens?	77	80	78

Sample sources:
1. 1060 first and second year students. Ohio State University, Columbus, Ohio.
2. 169 Undergraduate students, Erindale College, Missisauga, Ont., Canada.
3. 45 honors freshmen, University of Delaware, Dover, Del.

An Introduction to Energy Budgets and Ecosystem Models

Most text book examples of ecosystem analysis are in the form of block diagrams that specify the standing crop and rates of flux between compartments. It is not often that much attention is given to discussions of the ways these values are measured for models of energy relations. Consequently the diagrams often remain abstractions that are difficult to relate to things and processes in the real world. So long as that is true, students are unlikely to gain any appreciation of the strengths and weakness of the models as representations of the operations of communities in the real world.

In order to remedy, in part, that oversight as well as to set forth specific examples from the Indian situation, five readings have been selected. These examples define the basic biological functions on which energy budgets and ecosystem analyses are based and also specify how the basic data are collected and used to describe ecosystem functions. In each case a particular problem is defined and an analysis is developed for solving that particular problem. Thus, the papers stand as examples of how to solve problems by using energy budgets and ecosystem analysis, but the papers are not a blue print for imitation. It is the way the answers are worked out rather than the specific techniques that is most important lesson to consider.

The readings range from a purely biological study of a beetle to an analysis of fuels used by humans. They clearly show that biological functions are the basic functional elements of these systems. These papers give the details of analysis and a reader should verify the calculations in order to learn how to carry out comparable analyses.

Singh et al. (1976) develop an energy budget for a stored grain pest that is common throughout the world and does serious damage to grains in India. Each component of the energy budget is measured independently, and such measurements can accurately represent the energy expenditures of small animals that live relatively simple lives in a fairly uniform environment. These unusual traits are shown by stored grain insects. Animals that live complex lives and show a variety of behaviour patterns in a wide range of habitats cannot be analysed so easily. The problems are fairly easy to visualize if one considers that an individual of <u>Sitophilous</u> spends its life from egg to adult inside one seed of grain.

Even after emerging, the adult beetles live a life that is limited to mating, dispersal and oviposition. When life styles and habitat are very uniform an energy budget can be specified very precisely and will accurately portray the energetics of each individual. In contrast, the complex life of individual fishes, spiders, worms, birds or frogs differs widely from individual to individual and must be statistically characterised by a statistical range.

As is clear in Lee's (1966) study, the lives of the individual in a bunting gathering society differ greatly. There is no such a thing as a "typical" or average individual. A single adult could survive alone, just as an adult beetle survives alone, but a single adult female of the Kung bushman could not rear an offspring except as a member of a group that shares food. The group is essential for survival. The index "S" is used to measure independence in food. When "S" equals 1.0, each individual feeds itself and when "S" equals 0.2, as it sometimes does among the Kung, it means that only one out of five needs work to gather food which is then shared with the others. "S" is a measure of the division of labour and will be less than 1.0 for societies such as human societies in which some individuals do not collect food, and insect societies that have guards and non-foraging reproductives. "S" has a very special use and should not be confused with other aspects of sociality. Baboons with S = 1.0 are independent in that each individual collects its own food and does not share food. Yet the individuals are not independent in the sense that a single baboon could survive alone. The baboon troop increases the efficiency of foraging, provides warning of predators and greatly magnifies defensive responses. The individual needs these for survival. As energetic analyses are made, various indicies are worked out for efficiencies or yields. The index must fit the problem at hand and may not be appropriate in other contexts. As these papers are read it will be most useful to ask what problem is being considered and why a particular index or calculation is appropriate. This will allow an investigator to see how to develop techniques that are appropriate rather than to search for problems that fit someone else's techniques.

In studying bullocks in West Bengal, Odend'hal (1972) based his work on an energy budget for bullocks that was in principle, exactly the same as that of Singh et al. (1976) for <u>Sitophilous</u>. Studies of long lived, warm blooded vertebrates can be simplified because the cost of reproduction and growth is relatively small compared to the metabolic cost of maintaining the adult animal. Throughout most of the life of <u>Sitiphilous</u> the energy budget is:

Assimilation = Growth + Respiration
and two of the three factors have to be measured independently in order to specify the energy budget. But adult warm blooded animals, such as bullocks, do not grow. Because G = 0 the energy budget reduces to:

$$A = R$$

R is predictable from size with considerable accuracy. The main problem addressed by Odend' hall is the relation of input to output for a system in which it is of interest to know the foods (Ingested calories) relative to the useful products, dung and work, obtained from the bullocks.

Although the objectives of Odend'hal's (1972) study are very different from those of Singh _et al._ (1976) or Lee (1966), they all employ some aspect of an animal energy budget. The energy budget is the consistent biological base for all these studies and the principles apply as well to beetles and independent biological human systems as they do to the role of bullocks in the production system of a complex interacting human society.

But all these systems are purely biological. Human societies become more complex by releasing fossil solar energy as heat to produce physical and chemical changes - cooking, making pottery, extracting and shaping metals. These energy demands increase with social complexity. The energy of fossil fuel may substitute for biological energy (tractors replace bullocks and chemicals replace manure) or are used to alter biological relations (insecticides, herbicides). As the demands for thermal energy increase, society has drawn from the pool of non-renewable fossil fuel that is the store of solar energy from the past. The energy of coal and oil can be measured in exactly the same way as the energy of rice and groundnut oil, thus the inputs, whether they are inputs of current solar energy or fossil fuel can be expressed similarly. They do represent different categories of energy. Solar energy is a fixed input all systems receive as a function of their area and latitude but fossil fuel is in very unequally dispersed stores that are the result of geological peculiarities. Fossil fuels can be used only at a considerable economic cost that escalates as supplies dwindle. Thus some relationship between fossil fuel input and the output of food (both expressed as calories) has been used to measure what is variously

called the efficiency of production or its vulnerability to the external costs of fossil fuel. The best index is probably the simple ratio of food output:fossil fuel input. At 1:0 the country has a solar powered agriculture and at 1:2 the United States and Europe are vulnerable bedause they need 2 cals of fossil fuel inputs to produce a cal of food.

Pimentel et al. (1973) show how the concept of energy budgets applies to mechanized chemical agriculture. The contrast between this system and the almost purely biological systems of Indian agriculture will be taken up elsewhere. Pimentel et al. explain each of the constants and such explanations are absolutely essential for any study of energetics. The energy models are essential for the analysis of the complete system because all elements are specified in calories. But if there is a specific objective or an applied problem, it may be necessary to revert to units of mass rather than units of energy. For example, the energetic cost of nitrogen varies widely depending on the manufacturing process but the plants respond to the mass of nitrogen available and the energy consumed in the manufacture of a kg of nitrogen is irrelevant to the plant response. It is very important that equivalents be given in order to make data available for a variety of uses.

Alternate uses of dung are evaluated in Bhavani's (1976) paper and described in narrative style. It helps to tabulate the data so that it can be combined with information from Pomentel et al.(1973) to specify tradeoffs. That willbe taken up elsewhere. The Bhavani (1976) paper gives all the essential equivalents but it does not set the problem in context. For example, it is desirable to know how much heat energy a family unit requires and how this relates to the outputs of gas plants. When this is known, it will be possible to measure how much biogas is required and how many cattle are needed to supply an appropriate gas generator.

It is always necessary to fit the components together into the entire system because it is the relations within the system that set limits to the components. For this reason even a crude model with approximate values is useful in evaluating small scale studies of components.

Readings

1. An Energy Budget of <u>Sitophilous oryzae</u>
   (Coleoptera, Curculionidae.)
   J.P.Singh, A.Campbell and R.N.Sinha
   Annals Entom. Soc.Amer. 69: 503-512.

2. ! Kung Bushmen Subsistence: An Input-Output Analysis.
   Richard B.Lee
   In: Ecological Essays: Proceedings of the Conference of Cultural Ecology. David Damas, ed.
   National Museum of Canada, Mus.of Canada Bull. 230.

3. Energetics of Indian Cattle in their Environment
   Stewart Odend'hal
   Human Ecology 1: 3-22.

4. Food Production and the Energy Crisis
   David Pimentel, <u>et</u> <u>al</u>.
   Science 182: 443-449.

5. Biogas for Fuel and Fertilizer
   S.Bhavani
   Indian Journ.Agr.Econ. 31: 219-231.

(Unfortunately it was not possible to duplicate reading No.5)

III. Energy Budgets

The energy budget is a simple algebraic expression defining the fate of the energy received by an organism. Since energy is neither created nor destroyed, all the uses and the losses of energy by an organism must equal the energy taken in. One common expression for the energy budget is:

$$E\text{-}U = A = G + M$$ — for mammals — B.wt$^{0.7}$?

only for basal metabolism i.e. at rest

in which E is the energy received, U is the unassimilated energy that is either lost or not absorbed, A is the assimilated energy which must be used for either growth(G) or metabolism(M).

Plant Energy Budgets

In the case of plants energy is received as sunlight, which is fixed as chemical energy through the process of photosynthesis. Any physico-chemical process, such as photosynthesis, has an efficiency which defines the yield relative to the input. The input to photosynthesis is the kinetic energy of light and the output is the stored chemical energy in the form of organic carbon molecules. If conditions are specified, then the yield can be given with a coefficient for photosynthesis (Cp) which is Yield/Input or A/E. In general plants rarely have Cp greater than 0.02, hence, the maximum energy budget for a plant would be...

$$E \times Cp = A = G + M$$

$$E \times 0.02 = 0.02\,E = G + M$$

The photosynthetic coefficient gives the outcome of a complex interaction of the photosynthetic apparatus with environmental factors. Photosynthetic mechanisms fall into 3 categories: the Calvin cycle in which the first product is a C_3 sugar, the Hatch-Stack pathway in which a C_4 sugar is the first product and a pathway typical of succulents and plants of xeric conditions, crassolacean acid metabolism. The photosynthetic rates of these systems respond in different ways to temperature, water, and light intensity. Each system shares some general traits but there are considerable differences among the plants of a given type.

The Cp of a plant is affected by a set of primary factors that include 1) the photosynthetic mechanism, 2) water 3) temperature and 4) micronutrients. The response to each factor can be specified from laboratory experiments but it is not at all practical to predict Cp in nature from controlled laboratory experiments. While precise predictions

are difficult, it has still been possible to develop some general models relating to growth form and production (Miller, 1972). It does not appear that such an approach can be extended to a large number of species and account for secondary responses within the community that include 1) the growth form of the plant 2) competitions 3) allelopathic responses and 4) herbivory. Ecologists are hopeful of developing an analytical explanation but, at this time, an empirical approach is the best that can be done.

The best predictions of community structure are based on the correlations of communities with climate. If the temperature regimen and an index of water availability are specified, then the dominant growth form and the level of Net Primary Production (NPP) can be estimated.

The NPP can be divided into compartments so as to form a budget for the allocation of the energy available for growth.

$$NPP = G = R+S+L+P$$

The components are roots (R), stems and branches (S), leaves (L) and the reproductive organs and propagules (P).

The growth budget of each of the major growth forms tends to be quite uniform despite the fact that the plants with a given growth form may come from a wide variety of climates and communities with quite different structures. The extremes of community structure are the tree-dominated forests and the grasslands and the NPP of each community type may differ greatly, still, the growth budget of grasses and trees tends to be almost constant.

	Roots, Stem	Leaves	Propagules	Community NPP ($kg\ ha^{-1} gr^{-1}$)
Grasses				
Temperate	.16	.59	.25	500 - 15,000
Tropical	.22	.53	.25	100 - 12,000
Trees				
Temperate	.68	.30	.02	12,000 -13,000
Tropical	.70	.28	.02	15,000 -35,000

Tropical grasslands have a lower NPP because they are in zones that are more arid than the zones occupied by temperate grasslands. Despite the great differences in climate and the level of competition implied by NPP, the growth budgets of each category are virtually identical.

The product of a growth budget component times the NPP will give an index of the absolute abundance of various classes of resources and the resources can be grouped into classes of foods for animals. Roots and stems are basically cellulose that is consumed by microbial decomposers and a very limited set of animals. Leaves represent a very different set of molecules and are consumed by grazing herbivores. Reproductive organs and seeds are still another kind of food and this food is collected by a variety of animals. These animals are often called croppers.

The growth budget of plants defines the kind of resources that are available for animals and their density. Unfortunately the field data are nearly all limited to above-ground production. In the case of agricultural systems such data are adequate for defining the role of plants as resources because below ground production is not used (save for tubers and groundnuts). Livestock form the grazer community while man is a mixed cropper and carnivore.

Animal Energy Budgets

An alteration of terms is needed to define the feeding processes of an animal more precisely. It is best to use I (ingested) rather than E (energy absorbed) and designate the compartment U(unabsorbed) as F(feces). The substituted terms give an energy budget of

$$I - F = A = G + M$$

Metabolism is easily measured in animals and assumes a variety of roles. Basal metabolism (M_b) is the energy expended in simple maintenance at rest. When active, there is an increment in metabolism that can be defined as the cost of activity (Ma). The level of basal metabolism follows reasonably consistent patterns. In the case of mammals basal metabolism per day is fairly well predicted as:

$$M_b = 70W^{.75}$$

in which W is the wet weight and M_b is Kcal per day.

Metabolism can be shown to be a major component in animal energy budgets because it is both the largest single component and differences in activity(M_a) will define major quantitative differences associated with locomotor, feeding and defensive behavior. This is especially true for homeotherms. All warm blooded animals show determinant growth, that is, a fixed adult size is reached and the animal remains at that size for its entire life. The daily energy budget can be given as:

$$A = G + M$$

$$A = (W/\text{days})\ 2{,}500 + 70W^{.75}$$

in which the weight is divided by the life span in days and multiplied by the coefficients of 2,500 kcal per kg given as the average caloric value for the wet weight of animals (Odum, 1971). For oxen that live 5,475 days (15 years), the energetic value for G is so small compared to that of metabolism that it can be ignored. For humans with life expectancies of over 50 years G is even smaller.

The total ingested energy of humans and livestock may double with heavy labor which implies that M_a is generally less than M_b hence the relation between energy budget components for agricultural systems is:

$$G \ll M_b > M_a$$

More detailed empirical data are available for most of the components of agricultural systems so that the energy budgets can be given with very great precision.

Energy Budgets in Agriculture

Several simplifications are possible in agricultural systems. The growth budget data for plants are limited to above ground production and often given as a harvest index which is Food/Mass harvested. Grains are the major plants and the harvest index for grains is merely:

$$P/(S+L+P) = H_i$$

Note that the small amount of energy in flowers and husk is included in P. The harvest index (H_i) for a crop lets one estimate the yield of the crop as:

$$(\text{kg harvest}) \times H_i = \text{Kg crop}$$

and H_i falls between .24 and .57 for the common grains (Zeitlich, 1975). The mean of .38 is only slightly higher than the means of .30 and .32 for the wild grasses mentioned above.

In Indian agriculture the harvest residue is an essential product for the operation of the system. Straw is used as cattle food, and compact heavy stems may be used as fuel. In terms of resources, the growth budget of crops in agriculture should be broken down so as to define categories of NPP that are used as either human food, fuel, fodder, or to provide shelter. The growth budget categories used above generally appropriately define categories in the way farmers use them.

The needs for shelter include non-biotic materials, stone and earth, and are not only difficult to estimate but also a small component relative to food and fuel. In these preliminary studies shelter needs have not been estimated. Such demands should be determined in any detailed analysis.

As indicated above the energy budget for humans and livestock involves a trivial amount of growth, hence, the animal energy budgets can be treated as only slightly underestimated if given as metabolism.

Determining an Energy Budget

The energy budget must be secondarily derived from a mass budget because primary measurements of the calories of growth require the destruction of an animal and metabolism can be measured only on restrained animals. The direct caloric coefficients are obtained in the laboratory. These coefficients can then be used to convert field data on biomass and activity into calories.

An activity and mass budget must be obtained first. There is no way to check these budgets for accuracy because masses are not equivalent. A kg of dry plant material will average about 4,500 kcal but a kg of animal (dry) will be 5,500 kcal because of the higher protein and fat content of animals. The kcal/kg can be measured directly as heat when a piece of dry tissue is burned in an oxygen bomb. The equipment for bomb calorimetry is not always readily available and good estimates can be made a chemical analysis. Organic materials are made up of fats, carbohydrates and proteins and these three classes of molecules each have a very consistent relation between mass and stored chemical energy. The very large body of nutritional research relies mainly on chemical analysis and the conversion of mass data to calories. The equivalents are 4.15 kcal/gm for carbohydrate, protein 5.65 and fats 9.40.

Detailed data on caloric equivalents are given in the appendix of Part IV.

In agricultural systems there willbe some non-biological inputs that cannot be expressed in calories. A stone fence requires calories of energy to erect but the stones have no caloric value but the bamboo of a woven bamboo fence has a caloric value as bamboo NPP. The role of the fence is to reduce losses of the crop so that the fence might be indicated to have a value equal to the crop it saves. At times a component like a fence may be introduced merely to give completeness to the analysis by recording its value or cost to a community. At other times a specific analysis may be employed to test an idea.

For example, one might wish to test the idea that it labor is in short supply and it is a question of whether to put labor into fishing rather than fencing.

A problem such as this may not be solvable from energetic considerations alone. Protein is an essential dietary element. If it is abundant, then, the value of protein is merely its caloric content but if protein is scarce, then, its value may excede its caloric content by many times. In terms of calories, the pulses would never be grown, but as a protein source in India, they assume a value far greater than an equivalent calory of rice.

External biotic inputs, fertilizers, chemicals and irrigation, have no equivalents in terms of food kilocalories. One might argue that they have a value corresponding to the kcal of food they generate. This is very difficult to evaluate and will be considered elsewhere. The external inputs do have a common base for comparison and that is the kcal of fossil fuel needed to produce them. This is closely associated with the cost of the various external inputs to the farmer and is the best way to compare the relative cost of various inputs to the farmer and to society.

Nearly all these special problems of conversion can be easily resolved in a consistent fashion and they must be if an energy budget for an agricultural system is to be developed and tested for its completeness. The problems of the non-equivalence of fossil fuel calories with food calories or protein calories with fat or carbohydrate calories may be set aside in the construction and testing of an energy budget for its precision. They become crucial issues in the interpretation and use of an energy budget and so they will be taken up after the explicit examples of how energy budgets can be worked out.

Ecosystem Models in Agriculture

An ecosystem model is built by linking together a series of resource utilization models. A resource utilization model defines the way some ecosystem component (a trophic level, one species or a set of similar species) draws resources from the resource base and specifies how that resource input is used. A reasonably complete set of resource utilization models can be fit into an ecosystem model.

A resource utilization model can be specified for a Sal(Shorea robusta Gaetn.F.) forest in India (Misra, 1968). The resource base is solar energy. The energy of the resource base is not specified in the original, however, the general pattern of solar radiation is known and Budyoko's (1968) map indicates that the resource base of solar energy is about 1.75×10^{10} Kcal ha^{-1} yr^{-1}. Of that, 22.56×10^7 Kcal are captured over one ha of sal forest and can be expressed as:

Resource base = Resource absorbed by sal + Resource lost

$$1.75 \times 10^{10} = (22.56 \times 10^7) + (1.727 \times 10^{10})$$

The use of the absorbed energy can be expressed as:

Energy absorbed = Respiration + Biomass

$$22{,}558 = 17{,}894 + 4{,}451$$

Obviously the equation is unbalanced. Either the energy absorbed is too high or else respiration or biomass, or both are too low. If each of the three values is obtained independently by experimental means, it is unlikely that the data will be so accurate as to perfectly balance. In many studies the equations are solved to obtain one value. The equation $E = R + B$ can be solved if any two values are known and when that is done there is no way to verify any of the values. One just assumes that the two measured values are measured perfectly. Since that is unlikely, it is unwise to build ecosystem models if very many of the values are obtained as algebraic solutions rather than experimental measures.

The resource utilization model can be expanded further by dividing the biomass into its components:

Biomass = leaves + roots + trunks + stems + consumption by herbivores

This defines the allocation of growth and specifies the energy transferred to the next trophic level. This is the way in which resource utilization models may be linked up to produce a model for a complete ecosystem. It is a complex and difficult job to build up a model for a community or ecosystem and a specific model is not available for India.

It is possible to develop a general ecosystem model for Indian agriculture because caloric equivalents for most of the components of agricultural ecosystems are known. Before doing so it is necessary to ask whether such a model is likely to have any validity or utility.

Models for agriculture are concerned with three major compartments: i) the resources used by plants as they grow, ii) production of food and iii) the consumption of food. If an agricultural society is very closely tied to its food resources, it would be expected that the availability of the resources required by plants would determine the annual crop and the average annual crop of food would in turn be a limit that determines how large the population could be.

A mathematical statement of the relation is:

Population = f(Resources, Yields)

The causal elements of this relationship are two biological functions that interact sequentially. First, there is the use of resources by plants to produce crops. Second, the yields of crops, in turn, sustain the human population.

The resource-yield relation is a basic biological response of a crop plant that can be specified in great detail, such as Thompson (1975) did for yields of wheat in the United States. The relationships between resources and yields may be general enough that even complex pooled data, such as grain production in India, will show good correlations between the yield and an index for the rain received during the summer monsoon (Gavan and Dixon, 1975). A mathematical function for the resource-yield relationship can often be defined and it is reasonable to think that it may soon be possible to predict the responses of plants to resources with mathematical models based on elemental biological processes (Miller, 1972).

The relationship between crops and the population has been tested by Dandekar and Gadam (in press) in an analysis of the relationship between rural population density and land use. The density of the rural population is positively correlated with the areas in rice, wheat, pulses, sugar, fruits and vegetables and the correlation explains nearly 85 per cent of the variation in population density. The biological basis for the crop area - people relationship has yet to be examined.

The evidence is that the resource-crop relation is generally predictable and that the relation of population to crops also follows a general pattern. If these two relations are tightly coupled, then the population would correlate closely with the resources available for crops. Such correlations would be the basis for the most general model for an agricultural system. The value of models depends on their generality.

A general model relating resources to the human population is best tested for a set of areas that
i) differ widely in only one major resource.
ii) have primarily rural populations that neither import nor export significant quantities of agricultural produce iii) employ a similar technologies and iv) have populations with similar diets.

India is an ideal country for such a test. Innovations in technology are developed centrally by the Indian Council of Agricultural Research but each State has control over the implementation of agricultural policies and tends to be self-sufficient. Only ten per cent of the total cereal crop is exchanged between States by rail or river, and nearly all of that is wheat being moved from production areas in the north-west of India. The diets are basically vegetarian and the population mainly rural. Annual variations in temperature are not major factors in determining yields. Soils are important but not a major variable. The prime resource factor in India is rainfall, which ranges from a mean of about 35 cm in Rajasthan to 325 cm in Kerala. There is no surplus production and since 1970 over 95 per cent of the needs were met by production in India (Indian Agriculture in Brief, 1975).

Clearly India is well suited for a test of the generality of an energy flow model relating the resources of plants to the density of people. A test was based on Census data for 1961 when the effects of irrigation were less likely to confuse the situation with respect to water resources. A weighted estimate for normal rainfall was taken from data given by Sen Gupta (1971). These are long term (more than 70 years) averages. Small regions of high rainfall in four States were not averaged in (for example, Mangalore in Karnataka) and this potential source of bias was checked after the analysis was completed. There was no consistent pattern of deviation among the four States involved (Karnataka, Maharashtra, Tamil Nadu and Utter Pradesh).

The regression (Fig.1) accounts for 40 per cent of the variation. This is a remarkably good correlation considering the fact that the data cover very large geographic areas. It suggests that models for the relationship between resources and population may have a biological basis. It is reasonable to expect that energy flow models may usefully define agricultural processes and also characterize the alternatives open for agricultural development in India.

Models for Energy Flow

As is often the case in science, the models of greatest generality have been the product of pure research by scientists who had the leisure to pursue their general curiosity and had abstract knowledge as their major goal. The work of ecologists on simple closed aquatic ecosystems forms the basis for ecosystems models in ecology. This began with Lindeman's study (1942) of a temperate lake in which he showed how the flows of solar energy through green plants to herbivores and to carnivores could be described.

Some anthropologists have also followed the approach of using an energy budget to define the costs and benefits of behaviour in primitive societies. Lee's (1966) study of the ! Kung bushmen remains a model for such studies.

The reason for using energy is simple to explain. Each animal or plant needs to burn a certain quantity of organic carbon to maintain its body and this energy is easily measured as calories of respiration. The potential value of food as a fuel is rather easily estimated and the value of a given food is a constant because the carbon chemistry of all living things is similar.

The animal of importance in agriculture, man can survive on a minimum input of around 2000 Kcals a day and we know that about 90 per cent of that energy can be absorbed and used (Nat.Acad.Sci. 1966). If called upon to work, the energy input must be increased in proportion to the work done or else it will be drawn from stored reserves in the body. Thus, there is a rather consistent and simple correspondence between the mass of food and the quantity of life and work that can be supported as tabulated in Gopalan <u>et al</u> (1974).

When energy budgets are applied to agriculture, we are concerned about the human equation. Man raises food to survive and the benefits of cropping depends on man cropping at least as much as he needs to survive and harvest the next crop. In a developing country the problem is one of farmers producing enough for their needs and for the increase in their population, with a modest surplus of, may be as much as 25 per cent, to feed the urban population and to store as a reserve against disasters in crop production.

The correlation between rainfall and population developed above suggests that all states in India have similar efficiencies in agricultural production and it is reasonable, therefore to present a general model for Indian agriculture based on census data. This model can serve as a null hypothesis and is a useful for two reasons. i) The selection of census data provides a standard data base which can always be brought upto date ii) It gives average performance, hence, one state, one production method or any other subset can be compared to see the ways in which they differ from the average. iii) In addition to giving average performance the components specify relations which can be used to evaluate the elements of production across the country.

A General Energy Model for Indian Agriculture

At this time, it is more important to understand the elements of an energy model and the process of developing that model, than it is to have all the values perfectly worked out. Indeed, great precision is not needed for a general model. It is in specific models for a single village or a particular crop that exact values will be needed. This exercise will illustrate how an energy budget can be developed and will discuss the derivation of values for five compartments i) Primary inputs, which are sunlight, water and chemicals ii) Products, the yields of crops,

iii) Secondary outputs, animal products, iv) Consumption or other use of products, and v) Secondary inputs, which are the labour and recycled materials that are supported by, or derived from previous year's production and used to produce and harvest the current years production. Data from the 1970-71 census will be used because that is the most recent complete set of data available. Most of the data are taken from Indian Agriculture in Brief (IAB).

The general model is illustrated in Figure 2 and the account that follows is an explanation of how the values were calculated and how they may be tested for their accuracy.

1. Primary Inputs. These are determined by area. It is not always appreciated that the owner of a hectare of land buys a hectare of sunlight as well as a hectare of rain along with the soil.

Solar radiation differs from place to place and from season to season. Near Delhi the solar flux ranges from $3x\ 10^6$ Kcal $ha^{-1}day^{-1}$ to 6×10^6 Kcal $ha^{-1}day^{-1}$ but, in this case, the solar flux plays a small role in production because water is limiting at the times of the two extremes of solar flux (Varshney, 1972). Solar radiation may be a factor and it should be considered in detailed local studies.

When large areas are being considered, it is sufficient to use maps, such as those of Budyoko (1968), for general estimates. A hectare of sunlight in India receives about 1.75×10^{10} Kcal yr^{-1} (Budyoko, 1968) and this can be used to estimate the total energy received by the 148.4×10^6 ha of land cropped in India during 1970-71 (IAB) to be 2.60×10^{18} Kcal.

The other input will be from pasture. The permanent pasture in India is given as 14.8×10^6 ha (IAB), however, almost every patch of open ground in urban and rural areas is grazed and there is no easy way to get an accurate estimate of the total area that is actually grazed. For this analysis the area of pasture (that is the lands that are grazed) are assumed to be all lands except those classified as forests (66.0×10^6 ha), areas under non-agricultural use (16.2×10^6 ha), barren and unculturable land (29.2×10^6 ha) and land under crops. Sub-tracting these from the total reporting area of 305.3×10^6 ha gives a remainder of 45.5×10^6. That land is likely to be available and used for grazing. On an All-India basis, this is about equal to 0.3 of the crop lands. The total solar energy input into that area would then be 8.00×10^{17} Kcal yr^{-1}.

The cost of fertilizer and other chemicals consists of the fossil fuel energy used to mine and manufacture each component. This is best given as Kcal/kg of nutrient and values for fertilizers produced in the U.S.A. are given by Pimentel (1973), Avlani and Chancellor(1975) and Heichel (1976). Some very limited estimates for India were attempted by Senapatti (1976) but they are incomplete and not clearly documented. The Pimentel (1973) figures correspond to the values of Neichel (1976) but Pimentel gives values for N and P_2O_5 that are about 15 per cent greater than the Avlani and Chancellor (1975) values. The Pimentel (1973) values are used because they are the only complete and consistent set of caloric equivalents for all three nutrients. (See Appendix A for an example of the problems of estimating fertilizer costs). The inputs for India (Fertilizer Assoc. India, 1976) are.

	1971-72	Kcal/kgm	Total Input
N	1.8×10^9 kg	1.84×10^4	3.31×10^{13}
P_2O_5	5.6×10^8 kg	3.35×10^3	1.88×10^{12}
K_2O	3.0×10^8 kg	2.31×10^3	6.93×10^{11}
			3.57×10^{13}

Pesticides are treated as having 2.42×10^4 Kcal/kg (Pimentel et al. 1973)and the usage during 1970 was about 4.0×10^7 kg (United Nations, 1974) which gives an annual energy input of 9.68×10^{11} Kcal. The caloric equivalent for the herbicide 2-4 D is 3.54×10^4 (Avlani and Chancellor, 1975), but the use (1.4×10^5 kg) was so low that herbicides were included in the chemical total. The total caloric value for fertilizers and chemicals is 3.67×10^{13} Kcal.

Electrical power is the third major source of external energy and most of the energy consumed on farms is used to run electric water pumps. This represents 8.2×10^{12} Kcal (Ministry of Information and Broadcasting, 1974). Only half the pumps are electrical. The others are internal combustion engines which are probably half as efficient in terms of work per unit of fuel consumed. It is reasonable to estimate gas and diesel engines to use twice the Kcal of fuel as electrical engines. The estimated combined input of energy from electricity and petroleum is 2.46×10^{13} Kcal.

The energy used by the farmer may be a small fraction of the total caloric cost. A Kcal of electrical energy can be obtained from hydropower with little additional cost but energy produced from thermal sources, may require 2 or more Kcal of non-renewable fossil fuel

to be burned for each Kcal of electrical energy delivered. A complete record of the indirect costs of energy is difficult to obtain at this point. However, with the current interest in energetics, there is little doubt that more complete data will soon be available.

2. Production. The yields (IAB) can be pooled into major groups and the mean caloric equivalents from Gobalom *et al.* (1976) used to obtain the total production in calories.

Crop	Yield (10^9kg)	Caloric equivalent (Kcal Kg^{-1})	Kcal of production (10^{13})
Seed crops	113.91	3,474	39.60
Cotton, Jute, mesta	2.41	4,150*	1.00
Dry vegetables	1.58	2,995	.47
Tubers	13.07	819	1.07
Fresh fruits, vegetables	16.35	557	0.91
Gur	11.63	3,568	4.14
		Total	47.19
		Fiber	- 1.00
		Food	46.19

*Taken as the value for carbohydrate

It is much more difficult to estimate the vegetable wastes that are used as fuel. For example, much of the waste from cane is burned to produce gur and this is not accounted for above. Other plant parts are used as fuels and detailed data on such usages are difficult to obtain. Overall estimates for this energy were given in the regional handbook "India" for the Habitat Conference (Country Report: India, 1976). Only about 10 per cent of the commercial power generated in India is used domestically. The remaining 90 per cent comes from wood, vegetable waste and dung. It is estimated that about 5.28×10^{14} Kcal of vegetable wastes are used as fuel. This fuel is collected from both crop and pasture land.

The outputs from the pasture land are forage and the vegetable waste that is used as fuel and green manure. Neither of these can be taken from census values. There are

several ways to fill in such values. First a hectare receives 1.75×10^{10} Kcal of light energy a year and about 1-2 per cent of that energy appears in net production. In the case of grasses about half of their net production is in leaves, hence there will be 1.75×10^{10}Kcal $\times .015 \times .5 = 1.31 \times 10^8$ Kcal of leaves per ha. Actual estimates for above ground reproduction are much lower. Using the mean caloric content of harvested grass given by Singh and Ambasht (1975) for conversion the following estimates for the productivity of grazed areas are available for India.

Area	Source	Kcal $ha^{-1}(10^7)$
All India	CSIR. 1970	0.29
Varanasi	Singh, 1968	1.90
"	Singh, Ambasht, 1975a	1.31
"	" 1975b	4.73
Gir forest	Berwick, 1976	0.84
Gorakhpor	Sahai, <u>et al</u>.	4.11
	mean	= 2.20

This average is used (2.20×10^7 Kcal ha^{-1} yr^{-1}) $\times$ (45.5×10^6ha) to estimate a total yield of cattle forage of 1.00×10^{15} Kcal yr^{-1}.

Both pasturage and the by-products of food production, such as straw and oil cake, are fed to the animals producing dairy products, meat and eggs. Because these animals graze with little management, there are few estimates of their intake. Odend'hal(1972) gives the average intake for cattle in an area of West Bengal. Another estimate of intake can be calculated from CSIR (1970) Tables of the "available" livestock food for 1961. These data can be converted to mean caloric intake per animal with constants from Odend'hal(1972) for paddy straw(3272 Kcal mg^{-1}) and oil cake (4,244 Kcal kg^{-1}) and Pimentel et al.(1975) for green fodder (700 Kcal kg^{-1}). The C.S.I.R. data were then used to estimate the total consumption in Kcal.

	Annual intake (10^5 Kcal) Odend'hal (1972)	CSIR Table (1970)	1972 Population (10^6)	1972 Consumption (10^{14} Kcal)
Cattle				
Males over 3 years	79.2	109.6	74.6	8.176
Cows, milking	49.6	60.2	222.0	1.336
Cows, dry	49.6	43.8	34.5	1.511
Young	32.9	22.9	47.5	1.088
Buffalo				
Males over 3 Yrs.	-	86.1	8.1	.704
Cows, milking	-	103.6	15.2	1.575
Cows, dry	-	62.2	14.3	.889
Young	-	24.7	20.3	.501
Sheep	-	9.3	40.4	.376
Goats	-	8.8	68.0	.598
				16.743

About 20 per cent of the feed is estimated to be pasturage, hence, an estimated 3.4×10^{14} Kcal of pasturage is consumed and the mean estimates for pasture production were 1×10^{15} Kcal. The production figures varied widely and were either close to 1×10^7 Kcal ha^{-1} yr^{-1} or were above 4 Kcal ha^{-1} yr^{-1}. If the lower figure is more usual or representative then grassland production is inadequate to meet optimal feeding needs. If the upper value is most commonly achieved, then pasturage is adequate. In either case it would appear that there is likely to be very little surplus for fuel over and above pasturage needs. The remainder of the food for cattle, 13.3×10^{14} Kcal, must come from by-products of crops and represents 2.75 times as much calories as is harvested for food. It means that something of the order of 3 Kcal of straw, fodder and weeds must be collected for animal food for each calorie of crop that is harvested. The estimate for animal feed seems very high and may reflect that estimates for cattle food are based on better diets than most cattle receive. There is source for considerable error in many of these extrapolations but the general picture will not change unless there are errors of an order of magnitude or more.

The general conclusion supported independently by data on production and on consumption is that sheep, goats and cattle must eat a large fraction of the harvestable waste and may well require all the available pasturage in order to survive on a suboptimum diet. The demands for both animal food and for feed can be met only if nearly all primary production is harvested.

3. Secondary Outputs. The by-products of food, work and dung come from the livestock. The output of animal products used as food is:

Products	Quantity (10^9)	Caloric equivalent	Total Production (10^{12} Kcal)
Meat	.59 kg	1170 Kcal/kg	0.69
Milk	22.50 Kg	920 Kcal/kg	20.70
Eggs	7.7 eggs	70 Kcal/egg	0.54
			21.93

The caloric equivalents for meat and milk are from Gopalan et al. (1976) and the equivalent for eggs based on a 35 g egg with 13.3 per cent of each fat and protein (CSIR, 1970). This is a very small but qualitatively important contribution of protein to the diet. It is supplemented from external supplies via fisheries but that supplement was barely 10 per cent of the total protein (4.63×10^{11} Kcal of fish were produced in 1971) and probably not a major factor in the diets of most farmers.

The dung can be estimated as the unassimilated Kcals of animal food. It is generally held that about 20 per cent of the ingested Kcals are egested as feces which would be a yield of 3.35×10^{14} Kcal of dung per year. Independent census estimates of the use of dung as fuel give 3.26×10^{13} as the quantity burned and, while this is well below the estimates for collection of dung, which are as high as 75 per cent, it is not unlikely as an All-India figure.

With the energy crisis, the value of dung as both a fuel and as a fertilizer has become an important factor in national development and Bhavani(1975) reviewed the problem in detail. If burned, dung will deliver heat at 11 per cent efficiency, the nitrogen will be lost, but much of the phosphorus and potassium will be

retained in the ash. If dung is used as fertilizer, all the nutrients are recycled and, if used in gobar gas plants, heat and the nutrients are available. The following table gives the caloric values if one half the manure is collected in India.

Process	Heat Energy (10^{14})	Efficiency	Yield of Heat (10^{13}Kcal)	Fertilizer Caloric equivalents (10^{12} Kcal)		
				N	P_2O_5	K_2O
Burning	1.68	.11	1.81	-	7.2	4.0
Manure	-	-	-	42.0	7.2	4.0
Gobar Gas	0.60	.60	3.60	42.0	7.2	4.0

The fertilizer nutrient equivalents for dung are N = 1.6 per cent, P_2O_5 = 1.5 per cent and K_2O 1.2 per cent (Bhavani, 1976). The caloric equivalents for chemical fertilizer is based on Pimentel <u>et al</u>. (1973). It is clear that the use of half the dung as fertilizer provides nutrients equivalent to nearly twice the current fertilizer bill. The potential caloric value of gobar gas given above is of the order of 100 times the power input into agriculture. The technical problems and costs of gobar gas plants are not examined here. This only indicates maximum benefits without considering incidental costs.

The secondary product, fuel, can be estimated in three different ways and, thus, checks for internal consistency are possible. The quantity of dung burned as fuel is estimated as 3.28×10^{13} Kcal and 5.28×10^{14} Kcal of vegetable waste are used as fuel (Country Report: India, 1976). These are census-based estimates. The total available dung can be estimated independently because it is known that approximately 20 per cent of the calories ingested by cattle are egested as feces. That total is 3.35×10^{14} Kcal. A comparable theoretical yield of vegetable waste would be impractical as it would require having mass budgets for the above ground production for each crop and estimates of the alternative uses as cattle feed, bedding and manure.

A third estimate can be based on the requirements for fuel. It is estimated that each person would require $0.34m^3$ of gobar gas (4713 Kcal m^3) for cooking each day (Gobar gas, Why and How, 1975, Khadi and Village Industries Commission). If this is burned at an efficiency of 0.6 (Bhavani, 1976), then, the quantum of useful calories of heat per day would be:

$0.34 \times 4713 \times .6 = 961$ Kcal useful heat
and a total of 3.51×10^5 Kcal of useful heat would be needed per year. The 1971 population of 547.9 million would be expected to require:

$$(547.9 \times 10^6)(3.51 \times 10^5) = 1.923 \times 10^{14} \text{ Kcal useful heat.}$$

The contribution from the census estimates of dung actually burned would be:

$$(328 \times 10^{13})\ 0.11 = 3.59 \times 10^{12} \text{ Kcal}$$

and from vegetable waste there would be:

$$(5.28 \times 10^{14})\ 0.173 = 9.13 \times 10^3 \text{ Kcal}$$

A total yield of 9.48×10^{13} Kcal of useful cooking heat. This represents 49.3 per cent of the national needs and corresponds with independent estimates of fuel sources.

It is of interest to know the demands this fuel requirement places on the land. If the 1.923×10^{14} Kcal are from fuels that are burned with an efficiency of 15 per cent, then the total fuel Kcal required would be:

$$(1.923 \times 10^{14})\ (1/.15) = 1.28 \times 10^{15} \text{ Kcal of fuel}$$

Firewood contains 4,708 Kcal per kg (Khadi and Village Ind. Comm. 1975), ~~tk~~ is similar to other dry plant materials, therefore, the mass of fuel gathered would have to be:

$1.28 \times 10^{15}/4708 = 2.719 \times 10^{11}$ Kg of fuel which comes from 193.9×10^6 ha of crop and pasture land. This conservative estimate shows that 1,402 Kg of fuel must be collected from each hectare of land if agricultural wastes are to supply half the needs for cooking fuel in India. This represents a very large fraction of the annual productivity.

4. Consumption. Virtually all the food produced in India is consumed in India and one could directly allocate the crop production to the population. The validity of this can be tested with Kalirajan's (1976) estimates the caloric intake of various groups of Indians from the National Sample Survey Report on consumer purchases. These detailed data taken in 1963-69 give an indication of rural versus urban diets.

	Kcal per individual each year. (10^5 Kcal)	1970-71 Population (10^6)	Projected Consumption (10^{13} Kcal)
Rural	9.50	438.8	41.69
Urban	8.14	109.1	8.88
Total		547.9	50.57

The total estimated consumption of 5.06×10^{14} Kcal is only 5 per cent over the total of the crop yields and animal production, 4.84×10^{14}. Since the two estimates were independently derived from two different data sets, exact correspondence is not expected. This is a reasonably good fit for censuses and sample surveys. There are losses to rodents, during processing, and some export, as well as some gains from fishing and import, and these have not been entered into this analysis. It is known that production is very close to consumption and these data correspond with those facts.

5. Secondary Inputs The secondary inputs to agriculture are the labour of the rural population and bullocks. In some analyses only the metabolic cost of men and beast during work periods has been charged off as labour just as if animals were like electrical motors and used no power when idle. But animals burn nearly as much fuel when idle as when working and it willnot work to feed a bullock for working and store it on days when it is idle. Hence, the entire annual feed given to bullocks is the biological cost of their labour and, except for farmers with non-farming jobs, the food of all the rural population must be treated as a secondary input.

Of course the actual work output of draft animals can be given rather than their caloric intake. A bullock or a buffalo may develop an average of 0.75 hp (range 0.5 - 1.0) (Cockrill, 1974) which is the equivalent of 89 to 178 Kcal sec^{-1}. The actual work done by draft animals could be replaced by machines. Replacement by machines involves a loss of manurial resources and requires fossil fuel to produce, maintain and run the machine. Draft animals are solar powered. The major fuel they consume, straw, has no alternative use. Because of the variety of products from cattle an analysis of their value is a very complex problem. For this descriptive account only the biotic input has been considered.

Discussion

Census data suggests that the States of India can be visualized as a set of independent self-sufficient rural communities. All States seem to be governed by similar biological interactions that result in an increment of one person per hectare for each added 53 cms in mean rainfall. This gross oversimplification accounts for only a portion of the variation (40 per cent) but it is a sufficient basis for justifying the development of a general energy flow model from census data. The model presented here is only a very rough first approximation.

Such a model defines very broad overall patterns and efficiencies for agriculture in India. This is an average pattern and more precise models for real villages, regions or crop systems can be compared to this standard reference model. One would expect models of the real world to deviate from the reference model and such deviations can be measured and used to define patterns, trends and relative efficiencies in agriculture.

The general model can be used to show how theoretical yields can be estimated. For example, the total harvested crop of 2.35×10^{15} Kcal represents a caloric yield of 1.584 kcal m^{-2}. If one assumes that everything except the roots are harvested and the roots represent 0.25 of the standing crop, then this is a yield of 2,112 Kcal m^{-2}. This represents a very good yield for a semi-arid country (Rodin _et al_. 1975). It suggests that nearly all the natural resources are being used effectively. It would further suggest that Indian agriculture is operating at a rather high level of efficiency. This is especially true in terms of input. There is about 8 Kcal of food for each Kcal of Mechanical work or chemical put into the system. For most western agriculture the yield is 1 or 2 Kcal of food per Kcal of input.

The methods of determining the flows and exchanges of energy are the most important part of this paper. Very nearly all the constants are from India and there is reasonable consistency so the general picture for Indian agriculture may be reasonably well indicated. Still much of the data base is very inadequate and crucial sources may have been overlooked. As more data and more accurate data are gathered, it is essential to see that the energy flows are open to many different kinds of estimates. The basic algebra is:

Production = Crop + By-products

Crop = Waste + Consumed product

Consumed product = Assimilation + Defecation

Assimilation (adults) = Metabolism

There are known relations that define theoretical production for most crops and fairly fixed relations for ingestion and assimilation for animals. It is always possible to test observed performances against theory. It is almost always possible to obtain estimates in several different ways, as well. The accuracy and utility of an ecosystem analysis depends greatly on the ingenuity and imagination of the researcher.

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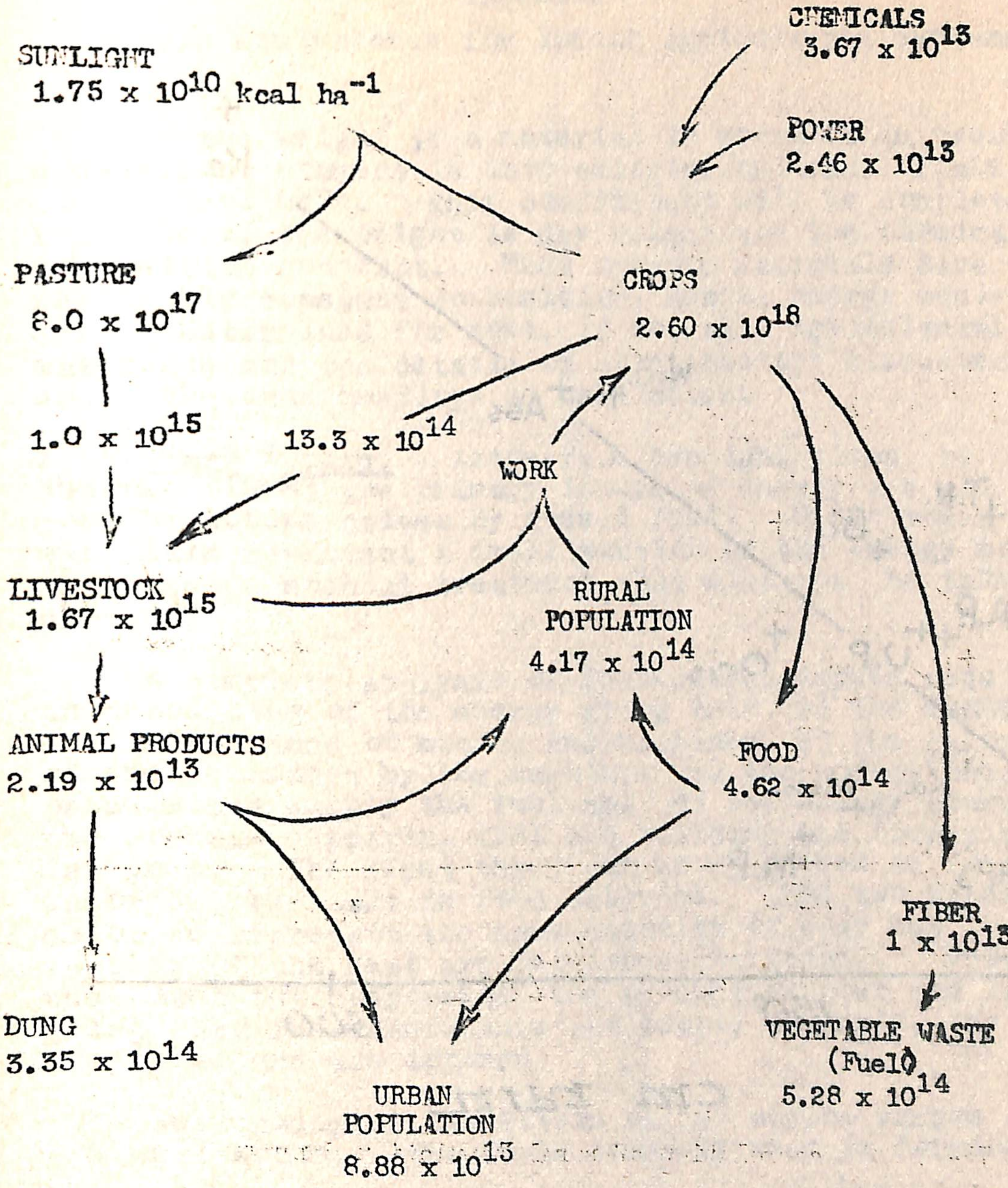

Figure IV-2. Energy flow in Indian agriculture.

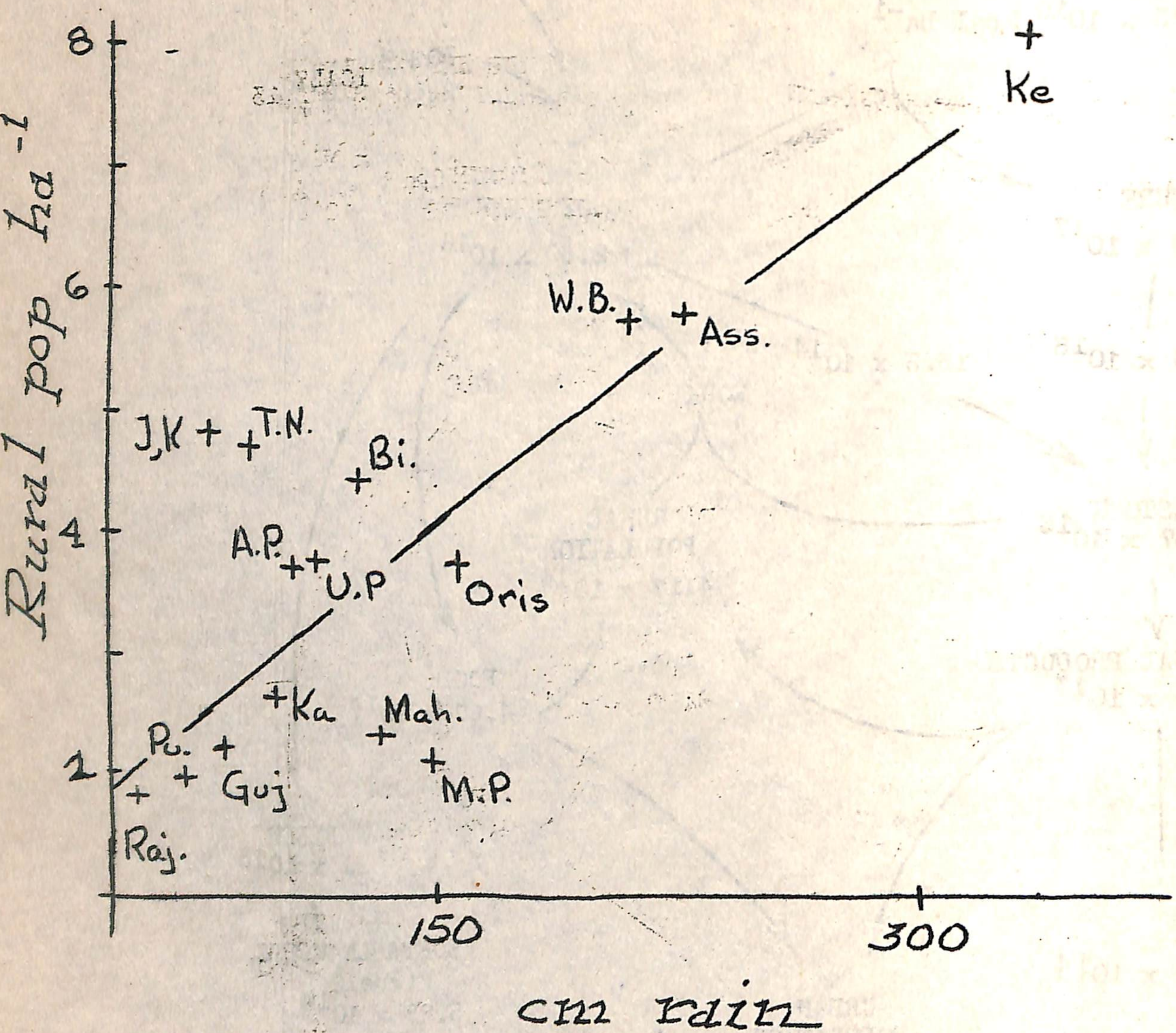

Figure IV-1. The correlation of rural population density with mean annual rainfall.

Appendix

Caloric Equivalents for Indian Agricultural Systems

If the weight of a material is known it is usually possible to convert it into calories by means of a coefficient kcal kg^{-1}. This coefficient will be completely reliable if the weight is dry weight and the chemical composition constant. Most organic materials have a reasonably constant composition, hence, energy equivalents can be determined for most, if not all, agricultural materials and the details of constants are discussed here under the same headings as used above.

1. Primary Inputs. Aside from sunlight given by Budgoko (1968) the primary inputs of energy are all work done by motors driven by fossil fuel. Hydro-power and windmills represent a small portion of the energy sources and require special treatment that will not be taken up here.

A complete analysis of fuel-driven inputs requires an accounting of the energy going into a) the manufacture and maintenance of motors and machines b) the calories of fuel consumed by the machines c) the energy needed to produce and supply the fuel and d) the energy consumed by the workers supplying fuel and building and operating the machines. The first three can be expressed as fossil fuel calories, the last is food calories. The two kinds of calories represent the same quantity of heat but the sources of the heat are not inter-changeable. Generally the last two components, the production cost and labor going into the manufacture and supply of fuels, are not available and are ignored.

Fuel calories lie within rather narrow ranges and are well known. The fuels commonly used in farming are:

	Conversion	Kcal kg^{-1}
Propane (C_3H_8)	18.392 fl^3 kg^{-1}	12,019
Aviation Petrol	2.664 kg gal^{-1}	11,863
Motor Petrol	2.804 kg gal^{-1}	11,669
Diesel	3.436 kg gal^{-1}	10,533
Kerosene	3.725 kg gal^{-1}	10,965

These values are taken from Pfafflin and Ziegler (1976) and Marks (1951). Differences of 10% can be found in these fuels due to differences in composition and specific gravity. Such differences are rarely likely to be major sources of error in the analysis of energy flow.

Electricity is given as Kilowatt-howas (Kwh) and one kwh = 860 Kcal.

If neither fuel consumption nor kwh can be obtained it is possible to specify inputs in terms of the work rating of motors because one horse power-hour equals 641.3 kcal. It is important to recognize that this measures only the work output of the motor and is far less than the energy used to drive the motor. Energy budgets based on the output of motors, rather than fuel input will underestimate the actual use of fossil fuel by a factor of as much as 3 or 4. The basis for estimating inputs of mechanical energy must always be made clear.

Machinery costs are very difficult to estimate. Pimentel et al. (1973) took the estimate of 31,968,000 kcal used to build a 1550 kg automobile and then calculated that machinery took 2.07×10^4 kcal kg^{-1}. Alternatively Avlani and Chancellor (1975) gave the cost of machinery as the energy inputs per dollar of machinery. The calorie inputs for one dollar of machinery were:

Refined petroleum	15,949
Electricity	4,690
Natural gas	24,270

	44,909 kcal per dollar

This fugure will be valid only if dollars and calories do not change or change together. Calories used to produce a unit weight of machines are likely to be constant unless manufacturing processes change radically, but the dollar relationship will fluctuare greatly with the market value of raw materials, especially fuel and labor. Only the Pimentel et al (1973) figure can be used now.

The annual cost of machinery must be the initial investment divided by the years of useful life plus maintenance costs. Generally only the original cost can be obtained and maintenance is difficult to estimate. There are few good estimates of machinery costs but this is not of great concern in work in India where machines are not used very much.

Fertilizers and Other Chemicals. Fixed values for production costs in the United States were given above. The energy cost of producing fertilizer in India would require knowing the energy used to:

a) obtain raw materials
b) transport raw materials
c) manufacture
d) distribution
e) application

Each of the five categories would require food energy for labor and fossil fuel for production of the machinery and fossil fuel to operate the machinery. This analysis would be complex because the heavy stationary machinery will have quite different costs than factors, and the crushing machines for phosphate are likely to have vastly different costs than the complex chemical plants making nitrogen compounds. There is an urgent need for good estimates of the energy used to produce fertilizers. Even a preliminary analysis of the fuel inputs for each unit of fertilizer would be useful but these data are evidently not available for India (Fertilizer Assoc. India, 1976).

2. Production. Excellent tables for all common Indian foods are available (Gopalan, et al. 1976). These are in terms of the weight of the purchased product and so they can be multiplied directly by the mass figures for crop production. Fresh vegetables and fruits will be more variable than dry products such as grains and pulses. The averages should be quite adequate for general studies. This breakdown is more detailed than that in the text.

Category	No. of values	Range Kcal Kg^{-1}	Average Water content	Average Kcal kg^{-1}
Grains	29	3,090-3,970	.114	3,481
Pulses	18	3,210-4,320	.111	3,646
Leaf vegetables (fresh)	107	220-1,150	.839	530
" (dry)	6	2,770-3,050	.086	2,983
Roots, tubers	40	160-1,930	.772	819
Vegetables (fresh)	69	90-1,150	.870	434
(dry)	16	229-4,720	.127	3,142
Fruits (fresh)	98	160-1,950	.802	707
" (dry)	5	2,150-3,290	.179	3,152
Fish (fresh)	87	590-2,730	.742	1,123
" (dry)	31	2,100-4,130	.162	3,058
Goat (muscle)	1	-	.742	1,180
Mutton (muscle)	1	-	.715	1,940
Milk, cows	1	-	.875	670
buffalo	1	-	.810	1,170
Gur	5	3,400-3,830	.083	3,568

It is often easier to obtain estimates of the composition of a food in terms of carbohydrate, fat and protein rather than direct calorimetry and the above data from Gopalam *et al*. are estimates from such extrapolations rather than direct calorimetry. Protein was considered to yield 5 Kcal gm^{-1}, carbohydrate 4 kcal gm^{-1} and fat 9 kcal gm^{-1}. The chemical energy of these three classes of carbon compounds is constant enough that more precise coefficients can be used with confidence and the following values should be used (Nat.Acad.Sci., 1966).

Protein	5.65	Kcal gm^{-1}
Carbohydrate	4.15	"
Fat	9.40	"

There are also excellently detailed tables for the plant products used as animal feed in India. Sen(1966) gives the chemical composition of over 1200 food items so that if one wished to break down an energy budget to individual food items, it is likely that the food composition could be obtained from the tables of Sen. Conversion to calories can be done with the above constants. The data given by Sen is by dry weight which avoids the problem of a variable water content. Agricultural data gives the weights of materials as harvested and so the data are converted into the calories per unit weight of feed.

Material	No. of values	Range Kcal kg^{-1}	Average water content	Average Kcal kg^{-1}
Green fodder	432	749.9-1,036.1	.75	942.5
Tree, shrub leaves	110	892.3-1,088.5	.75	1,001.1
Silage	17	1,072.5-1,221.6	.70	1,149.6
Hay	120	3,186.8-3,731.0	.10	3,465.5
Legume hay	14	3,374.9-3,736.7	.10	3,567.7
Straw	77	2,833.3-3,624.8	.10	3,330.4
Concentrates	76	2,943.6-3,436.3	.10	3,304.3
Cakes, meals	43	3,925.3-4,572.2	.10	4,341.1

The caloric values for broad categories of animal feed fall within a fairly narrow range. The extremes are usually no more than a 10 per cent departure from the average and even the most variable, straw and green fodder, have the extremes no more than a 15% departure from the mean. The food stuffs for man are much more variable. The ranges for vegetables and fruits are one or two times the mean and even the seeds show deviations of 15 per cent from the mean. Therefore, it would be desirable to pay particular attention to the kinds of food used by the human population. The analysis of animal feed is less likely to be a source of error if only broad

categories are used.

In addition to food, a portion of the primary production may be used as fuel. Coarse straw is often burned as a fuel. Dung is a secondary output although derived from primary production. For comparative purposes, all of the common cooking fuels are listed here.

Material	Reference	Kcal kg^{-1}	Notes
Anthracite coal	Lauge 1967	6,630	Av. of 9 values
Bitominous coal	"	7,185	Av. of 53 values
Lignite	"	3,624	Av. of 5 values
Peat	"	1,094	Av. of 6 values
Gobar gas	Khadi, Village Ind. 1975	-	4713 kcal m^3
Straw	Sen, 1966	3,340	Av. of 77 values
Wood	Khadi, Village Ind. 1975	4,708	-
Kerosine	"	11,124	1 kg = 0.82 liter
Charcoal	"	6,930	-
Dung cake	"	2,092	-

3. Secondary Outputs. The caloric equivalents of meat and milk were given with other foods. The leaves fuel, work and dung to be considered.

Work by draft animals involves the maintenance cost plus an increment for labor. Since the animal must be fed every day, the annual maintenance is a fixed cost and the increment needed for labor must be added. In the case of bullocks Sen (1966) gives the data from which the following values were obtained.

Bullock	Annual Maintenance	Daily Maintenance	Increment needed per day Light work	Heavy work
300 kg	3.087×10^6 Kcal	8,458 Kcal	4,902 Kcal	8,772 Kcal
400 kg	3.947×10^6 "	10,814 Kcal	6,461 Kcal	9,661 Kcal
500 kg	5.033×10^6 "	13,790 Kcal	7,385 Kcal	13,835 Kcal

These give the fuel costs of bullock labor and the output, which depends on weight and condition, will range from 0.5 to 1.0 horsepower hour which is equivalent to 321 to 641 Kcal (Cockrill, 1974).

At light work over a 10 hour day, a 500 kg bullock produces about 3,210 kcal of useful energy for an input of 21,175 kcal of feed. This is about a 15 per cent conversion rate and is what would be obtained if the bullock works every day. When there are days of rest the maintenance cost must be apportioned over the working days which will reduce the efficiency even more. It is likely that conversion rates of 5 to 10 per cent are common.

While the efficiency is low, the food source is largely straw that has no other alternative use, save as a manure. The labor supported by straw is a net gain for the system because cals of no value are converted into useful work. The cattle do need a small supplement but the concentrates and cakes fed to cattle are generally byproducts from processing grain or pressing oil. Concentrates may be in limited supply but they cannot be used for things other than animal food.

The energy required by the cattle is derived from carbohydrates and fats while the protein with its nitrogen and other micronutrients are turned over in the body of the animal, hence, very nearly all the nitrogen, phosphorus and potassium is recoverable in the dung and can be used for fertilizer. Dung, therefor, returns virtually all the useful micronutrients of the feed back to the system. The micronutrients of manure must be measured in units of mass because plants respond to the quantities present. The energetic value of dung is important in two ways. It can be burned to give heat and its value as a fuel is, of course, a simple property of its chemical energy content. Secondly the micronutrients represent materials that would otherwise have to be provided as chemical fertilizer at caloric costs explained above, hence, the micronutrients can be evaluated in terms of the fossil fuel energy they save.

The composition of fresh cattle dung and dung cakes are given as:

	Proportion			
	Water	N	P_2O_5	K_2O
Morrison (1957)	.78-.79	.005-.007	.001-.002	.004
Bhavani (1976)	.10	.016	.015	.012
Neelakantan(1975)	.80	.0008	.0010	.0010

The values for nitrogen in the dung from the United States (Morrison,1957) probably reflect the better diet of American cattle. The daily production of dung has been

estimated for each State (Neelakantan, 1975) and the All India average is 11.3 kg per day for cattle and 11.6 kg for buffalo. Neelakantan (1975) also gives estimates for the disposal of the dung that is collected.

The mass of farm yard manure is the statistic most often available for the analysis of agricultural systems and farm yard manure is a mixture of dung, straw and any other waste materials at hand. Its composition varies but three estimates have been found for the nutrient composition.

	Proportion N	Proportion P_2O_5	Proportion K_2O
Wood (1920)	.0058	.0021	.0058
Mariakulandai and Manickam (1975)	.005	.002	.005
Fert. Assoc. India, (1976)	.005-.015	.004-.008	.005-.019

The conversion of dung into gobar gas is a process described in a practical way (Khadi and Village Indust. Comm., 1975) and subjected to a sound theoretical analysis by Bhavani (1976), Neelakantan (1975 and in Press) has made a very careful analysis of manurial resources and regional differences in gas yield. The regional differences are very great and must be taken into account in any analysis of a particular region or system. These regional differences are largely due to temperature, although the breed of cattle and feeding traits are also important variables. The range of values for the States of India given by Neelakantan (1975) are:

	Daily Dung production Cattle	Daily Dung production Buffalo	Gobar gas production (m^3 ton of dung)
Minimum	3.62	4.82	23.2
Maximum	18.56	20.55	82.7
Average	11.30	11.60	67.1

4. <u>Consumption.</u> Kalirajan (1976) gives the caloric intake on a state level for India and the qualitative problems are discussed in detail in Gopalum *et al.* 1976. Sen (1966) gives a detailed discussion of the qualitative needs of cattle while Neelakantan (in press) has a state-wise break down of available feed.

All the values above give the chemical energy of foods. That is the total heat that will be released with complete combustion. That is the maximum usable energy. The usable energy is always less than the chemical energy. All animals must have a certain daily intake of protein for the maintenance of their body as well as the trace micronutrients. If these minor needs are not met, then the animal cannot survive even though the caloric requirements are met.

The biological value of organic carbon is affected by the physiological state of the animal, the mixture of foods it receives, as well as meeting the availability of protein and micronutrients. These interactions may have major effects on the availability of calories from a given food. A certain proportion of many foods is crude fiber that cannot be digested and an indication of the differences between the total calories and the readily digested materials in cattle feeds can be obtained from Sen (1966).

Kcal kg^{-1} of feed material (normal weight)

	Total Chemical Energy	Digestable
Green food	942.5	612.6
Grass hays	3465.5	1854.0
Legume hays	3567.7	2045.4
Cakes, meals	4341.1	3384.2

These are overall averages and it will be seen that the digestable kcals range from about half to nearly three-quarters of the total kcals.

It is important to see that the measures of chemical energy are the maximum figures. While refinement may not be useful in general models, it is essential to consider these factors when working out the details of specific systems. It is especially important factor in making recommendations. This entire problem is a difficult one that is not yet resolved even for human nutrition. The problem is usually avoided by giving the calories an animal normally ingests rather than the assimilable calories an animal requires.

Fuel is another item of consumption that is important. It must come from primary production and plays a significant role in converting some foods to a more digestable form. Fuels differ greatly in their efficiency and so the needs of fuel are best expressed in terms of useful heat. 640.8 kcal of useful heat are needed to cook for one person for one day. Using this value for cooking from the Khadi and Village Industries Comm. (1975), and other data from the same source, the needs of the various fuels can be given.

Fuel	Caloric value	Efficiency	Fuel needed per day.
Firewood(kg)	4708	.173	0.79
Straw (kg)	3340	.150*	1.28
Dung cake (kg)	2092	.110	2.78
Soft cake (kg)	6292	.280	0.36
Gobar gas (M^3)	4713	.600	0.23
Electricity(Kwh)	860	.700	1.06

5. <u>Secondary Inputs</u>. The labor of bullocks was discussed together with the secondary outputs under (3) above.

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